Its not all about sprinting: mechanisms of acute hamstring strain injuries in professional male rugby union—a systematic visual video analysis

Fearghal Kerin ,[1,2] Garreth Farrell,[3] Peter Tierney ,[4] Ulrik McCarthy Persson,[5] Giuseppe De Vito,[6] Eamonn Delahunt [7]

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[1]Fearghal Kerin, Leinster Rugby, Dublin, Ireland
[2]Fearghal Kerin, University College Dublin, Dublin, Ireland
[3]Leinster Rugby, Dublin, Ireland
[4]Sports Science, Football Association, London, UK
[5]School of Public Health Physiotherapy & Sports Science, University College Dublin, Dublin, Ireland
[6]Department of Biomedical Sciences, University of Padova School of Sciences, Padova, Veneto, Italy
[7]School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland

Correspondence to
Fearghal Kerin, Fearghal Kerin, Leinster Rugby, Dublin 4, Ireland; Fearghal.Kerin@leinsterrugby.ie

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ABSTRACT

Objectives The mechanisms of hamstring strain injuries (HSIs) in professional Rugby Union are not well understood. The aim of this study was to describe the mechanisms of HSIs in male professional Rugby Union players using video analysis.

Methods All time-loss acute HSIs identified via retrospective analysis of the Leinster Rugby injury surveillance database across the 2015/2016 to 2017/2018 seasons were considered as potentially eligible for inclusion. Three chartered physiotherapists (analysts) independently assessed all videos with a consensus meeting convened to describe the injury mechanisms. The determination of the injury mechanisms was based on an inductive process informed by a critical review of HSI mechanism literature (including kinematics, kinetics and muscle activity). One of the analysts also developed a qualitative description of each injury mechanism.

Results Seventeen acute HSIs were included in this study. Twelve per cent of the injuries were sustained during training with the remainder sustained during match-play. One HSI occurred due to direct contact to the injured muscle. The remainder were classified as indirect contact (ie, contact to another body region) or non-contact. These HSIs were sustained during five distinct actions—'running' (47%), 'decelerating' (18%), 'kicking' (6%), during a 'tackle' (6%) and 'rucking' (18%). The most common biomechanical presentation of the injured limb was characterised by trunk flexion with concomitant active knee extension (76%). Fifty per cent of cases also involved ipsilateral trunk rotation.

Conclusion HSIs in this study of Rugby Union were sustained during a number of playing situations and not just during sprinting. We identified a number of injury mechanisms including: 'running', 'decelerating', 'kicking', 'tackle', 'rucking' and 'direct trauma'. Hamstring muscle lengthening, characterised by trunk flexion and relative knee extension, appears to be a fundamental characteristic of the mechanisms of acute HSIs in Rugby Union.

INTRODUCTION

Hamstring strain injuries (HSIs) are the most prevalent muscle injury sustained by professional field-sport athletes.[1–6] They have been shown to account for 12% of all injuries in elite Rugby Union ('rugby') and soccer with recurrence rates of 23%–30% reported.[7 8] Two distinct types of HSIs have been described in the published literature; those that occur during sprinting (sprint-type) and those that occur as a result of an 'over-stretch' (stretch-type).[9] It is generally agreed that the sprint type of HSIs is sustained via an eccentric overload during the terminal swing phase of high velocity running.[10] During this phase of running, the biceps femoris long head exhibits the greatest elongation of the hamstring muscles, reaching almost 110% of its resting length.[11] The semimembranosus and semitendinosus muscles lengthen to 107% and 108% of their resting lengths, respectively.[11] Askling *et al*[12] demonstrated that all first-time acute HSIs sustained by sprinters primarily involved the biceps femoris long head. The stretch type of HSIs typically occur as a result of an over-stretch in a position of knee extension and trunk flexion,[13] which may be compounded by hip abduction.[14] This has been shown to more frequently involve the semimembranosus muscle (83%).[15]

HSIs are the most commonly sustained non-contact lower limb injury in rugby,[7] particularly among 'backs' for whom they have the highest injury incidence (0.30 injuries/1000 hours). Rugby Union is a collision sport, which requires players to tackle, evade, kick and sprint.[16 17] There are 15 players on a team—seven backs and eight forwards. Backs are typically lighter and quicker and are expected to carry out more sprinting and high-speed running than forwards, who in addition to running, may be expected to participate in more tackling, grappling and set-piece activities.[7] As a result, although the majority of HSIs in rugby have consistently been shown to occur during high-speed running,[7 18 19] the demands of the sport may provide an environment for which both the sprint-type and stretch-type HSIs can occur. In Australian football players, 81% of HSIs occur during high-speed running, with the remaining 19% during kicking,[20] while it has long been suggested that another common mechanism of injury involves picking the ball from ground.[21]

Video analysis is currently used in Rugby Union to assist match officials in making on-field decisions as well as in determining the severity of head injuries through the head injury assessment process.[22] Retrospective video analyses have been published describing the mechanisms of anterior cruciate ligament injuries and shoulder dislocations in rugby.[23 24] Serner *et al*,[25] to our knowledge, are the only research group to describe the mechanisms of acute muscle injuries using a video analysis approach—they reported on 17 adductor longus strains sustained by professional football (soccer) players. If the prevalence of HSIs in Rugby Union is to be reduced, it is imperative to gain a more complete understanding of the situations during which players sustain these injuries during training and/or match-play.[26] This could lead to the implementation of more optimal injury prevention initiatives. The objective of our study was to analyse and describe the mechanisms of acute HSIs in male professional Rugby Union players using video analysis.

METHODS

Injury inclusion

Leinster Rugby maintains an injury surveillance database, which records all injuries involving male senior and academy players across the entire competitive season, including preseason (eg, July 2017 to May 2018). All time-loss HSIs identified via retrospective analysis of the database across the 2015/16 to 2017/18 seasons were considered as potentially eligible for inclusion. We accessed the Leinster Rugby match and training video records to retrieve video footage of the match or training session, during which each HSI was sustained. One of the authors (FK) used data from the injury surveillance database (time of injury during match or training) to identify each HSI event.

Video acquisition and processing

Video footage of the instances during which the HSIs were sustained were sourced from the Leinster Rugby match and training video database—this video database also included national team matches. The videos were cut to blocks of 10 s preceding the HSI to the subsequent stop in play—an approach previously used in the analysis of adductor longus strains sustained by professional football players.[21] These were then converted to MPEG-4 files, which allowed frame-by-frame review at a frequency of 25 frames-per-second using QuickTime Player (V.7, Apple, Cupertino, California). Shorter clips of the HSI incidents were subsequently created, which, depending on availability, in some cases included multiple angles.

Determination of index frame

Three chartered physiotherapists (analysts) participated in the video analysis (FK, GF, ED). At the time of writing this article, the lead author (FK) was a PhD student with the primary focus of his thesis being HSIs in Rugby Union. The PhD programme of research was supported by an Employment-Based scholarship (via the Irish Research Council), with the employment partner being Leinster Rugby. At the time of writing this article, the lead author was employed as a Rehabilitation Chartered Physiotherapist with Leinster Rugby, while the second analyst (GF) was employed by Leinster Rugby as Head Chartered Physiotherapist and also functioned as the lead author's employment mentor. At the time of writing this article, the third analyst (ED) was the lead author's PhD supervisor. Prior to the completion of data analysis for this study, all three analysts meet in person during a 'study day' to review and discuss the literature on the proposed mechanisms of HSIs in sports. This 'study day' was underpinned by a narrative review completed by the lead author. Seminal research in the area relating to kinematics, kinetics and muscle activity (ie, surface electromyography) was critically evaluated and discussed.[11 27–31] This process resulted in an inductive approach to the analysis of the injury videos and the determination of the index frame (IF)—classified as the probable injury event—in which it was most likely that the HSI occurred.

The analysts independently assessed all videos in real-time and then frame-by-frame to record the estimated IF. Subsequently, a meeting was convened during which the analysts discussed and reached consensus on the IF. Consensus was achieved if two of the three analysts agreed on the IF. If consensus could not be reached, the case was excluded from this study. A similar approach to the identification and development of consensus regarding, the IF has been previously used in video analysis studies evaluating the mechanisms of injuries in different sports.[32–35]

Standardised injury analysis form

The three analysts developed a standardised injury analysis form (online supplemental file 1) as follows. Initially, a subset of the injuries were viewed and the analysts considered aspects of these injuries that may be specific to HSIs in Rugby Union (eg, 'jackaling'—defined as 'competing for the ball using the hands'). The analysts then reviewed other injury assessment forms detailed in previously published video analysis studies.[23–25 32] We used the classifications described by Waldén *et al*[32] to define a non-contact injury as one occurring with no bodily contact with another player in the IF. Contact to any other body region other than the injured leg was referred to as indirect contact, while contact to the injured leg was defined as direct contact.

For injuries occurring during 'tackle' or 'ruck' actions, the recommendations of the Rugby Union Video Analysis Consensus group were used.[22] This combined approach allowed us to describe the playing situation, player behaviour and whole-body kinematics of the injured player, in addition to Rugby Union-specific variables particularly related to ball carrying and contact scenarios. The analysts independently assessed all videos in real-time and frame-by-frame and then completed a standardised injury analysis form for each injury. Following completion of this step, a meeting was convened during which the analysts discussed and reached consensus on the variables within the standardised injury analysis forms.

First descriptive information on the HSI was captured—the type of event, pitch condition, position on pitch and playing situation. Then, the player's actions at the time of HSI were described—this included descriptions of kicking, running, change of direction, tackle and contact events. Thereafter, we described the biomechanical position of the injured player for the trunk, pelvis, hip (injured and uninjured) and knee (injured and uninjured) in each plane if possible.

Additionally, one of the analysts (ED) developed a qualitative description of each HSI mechanism, which was approved by all other authors (online supplemental file 2). Images of a number of the injuries are included as a supplemental file (online supplemental file 3).

RESULTS

Of the 51 hamstring injuries recorded in the Leinster Rugby injury surveillance database across the 2015/2016 to 2017/2018 seasons, 17 were included in this study (figure 1). Three players had more than one injury that were included in the final analysis. Each player (mean; player age=27±5 years, range 19–37 years; height=1.88±0.06 m, range=1.80–1.98 m; body mass=102±11 kg, range=93–126 kg) was contracted with Leinster Rugby, a professional Rugby Union team registered in the Ireland, who participate in the PRO14 and European Rugby Champions Cup. Five HSIs were sustained by players whose playing position was prop, 1 by a hooker, 6 by back rows, 3 by wings and 2 by full backs. MRI findings, using the British Athletics Muscle Injury Classification[36] were available for 15 of the cases (table 1). The biceps femoris muscle was the most frequently injured muscle (n=9).

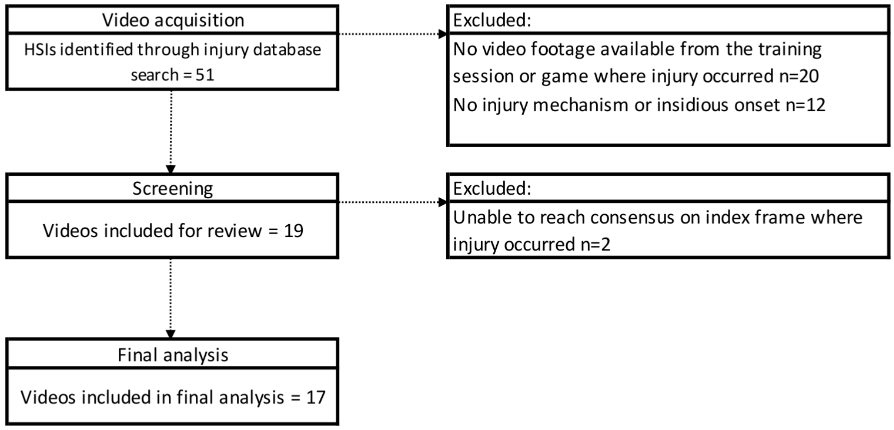

Figure 1 Flowchart describing the acquisition and screening process.

Ninety-four per cent of injuries were sustained on grass surfaces with 6% sustained on artificial grass surfaces. Twelve per cent of injuries were sustained during training with the remainder sustained during match-play (41% of injuries were sustained during the 21st and 40th min of match-play) (table 2). Of the excluded injuries, 42% occurred during training. Injuries sustained during offensive situations were more common (65%) than defensive (29%), with one injury (6%) sustained as part of a set piece (table 3).

One direct contact HSI was sustained as a result of 'direct trauma' (6%). Non-contact injuries were sustained during five distinct actions—'running' (47%), 'decelerating' (18%), 'kicking' (6%), during a 'tackle' (6%) and 'rucking' (18%) (table 4). Each of the injuries that involved a change of direction occurred while the athlete turned away from the injured side (n=7). Nine of the 11 injuries that occurred during locomotion (running and decelerating) were deemed to have occurred during the late swing phase.

In each indirect or non-contact scenario, the knee of the injured limb was undergoing angular extension. The hip was deemed to be extending in all cases, except for during 'tackle' and 'rucking' mechanisms, where the injured limb was forced into flexion.

In all non-contact or indirect contact cases, the player was in a position of trunk flexion at the IF (table 4). Trunk rotation was commonly observed, with 8 (50%) injuries characterised by rotation towards the injured (ipsilateral) side at the IF. Seventy-five per cent of the 'running' injuries involved ipsilateral trunk rotation. Twelve per cent of all injuries were characterised by contralateral trunk rotation at the IF (table 4). In 88% of cases, the knee was deemed to be in extension or in a position of shallow knee flexion.

Table 1 Injury classification according to BAMIC and involved muscle

Case	Side	BAMIC Classification	Muscle
Running			
1	Left	1a	Biceps femoris short head
2	Left	3c	Biceps femoris long head
3	Left	2 (no BAMIC at this location)	Biceps femoris interface of short and long head
4	Right	n/a	n/a
5	Left	3c	Semitendinosus
6	Right	1a	Semitendinosus
7	Right	2–3b	Biceps femoris long head
8	Right	2c	Biceps femoris and semitendosis common origin
Kicking			
9	Left	2b	Semimembranosus
Decelerating			
10	Left	1c	Biceps femoris long head
11	Right	n/a	n/a
12	Right	1a	Biceps femoris long head
Tackle			
13	Left	3c	Semimembranosus
Ruck			
14	Right	2b	Semimembranosus and biceps femoris
15	Right	3c	Semimembranosis
16	Left	3c	Semimembranosis
Direct trauma			
17	Right	1c	Biceps femoris short head

BAMIC, British Athletic Muscle Injury Classification.

Table 2 Descriptive information about injury situation

Case	Pitch type	Surface condition	End of pitch	Side of pitch	Playing situation	Type of play	Time in match
Running							
1	Grass	Normal	Opponent mid-quarter	Right	Offensive	In play	21–40
2	Artificial	Normal	Opponent mid-quarter	Left	Offensive	In play	41–60
3	Grass	Normal	Own 22	Right	Offensive	In play	Training
4	Grass	Normal	Own 22	Left	Defensive	In play	21–40
5	Grass	Normal	Opponents 22	Right	Offensive	In play	21–40
6	Grass	Normal	Own 22	Right	Defensive	In play	21–40
7	Grass	Normal	Opponents 22	Left	Offensive	Set play	61–80
8	Grass	Normal	Opponent mid-quarter	Central	Offensive	In play	1–20
Kicking							
9	Grass	Normal	Opponent mid-quarter	Right	Offensive	In play	61–80
Decelerating							
10	Grass	Normal	Own mid-quarter	Right	Offensive	In play	1–20
11	Grass	Dry	Opponent mid-quarter	Left	Defensive	In play	Training
12	Grass	Normal	Own mid-quarter	Right	Defensive	In play	1–20
Tackle							
13	Grass	Dry	Opponent mid-quarter	Central	Offensive	In play	41–60
Ruck							
14	Grass	Normal	Own 22	Right	Defensive	In play	21–40
15	Grass	Normal	Own 22	Right	Defensive	In play	21–40
16	Grass	Normal	Own mid-quarter	Right	Defensive	In play	41–60
Direct trauma							
17	Grass	Normal	Opponents 22	Right	Offensive	In play	41–60

DISCUSSION

HSIs in this study of Rugby Union were sustained during a number of playing situations and not just during sprinting. We identified a number of injury mechanisms, including 'running', 'decelerating', 'kicking', 'tackle', 'rucking' and 'direct trauma'. Hamstring muscle lengthening, characterised by trunk flexion and relative knee extension, appears to be a fundamental characteristic of the mechanisms of acute HSIs in rugby union.

This is the first reported video analysis study to describe the potential/probable mechanisms of acute HSI in male professional rugby players. The acute HSIs included in our study were sourced from the Leinster Rugby injury surveillance database and match/training video database. Video analysis studies have been used with increasing frequency to elucidate the mechanism of ligament and soft tissue injuries.[23–25 32–35 37] Such studies provide expanded descriptions of scenarios within match-play that precipitate injury and may influence injury risk stratification. The findings also provide critical insight into the biomechanical variables associated with the injury position and how these interact with our understanding of tissue failure. HSI-specific and sports-specific insights are difficult to gather using any other method. This study has illustrated that the potential/probable mechanism of HSI can be described using retrospective video analysis in rugby, and that specific patterns can be identified and that may be useful in tailoring injury prevention practices and establishing adaptations in rules or practices that may make the sport safer.

Running

Forty-seven per cent of injuries (8/17) were sustained while running. In all instances, we visually determined that the IF occurred while the player was accelerating rather than during maximum velocity running. In order to verify this observation, we recommend that future visual video analysis studies of the mechanisms of acute hamstring injuries in field sports should incorporate accelerometer data, with data being normalised to individual player speed thresholds as recommended by Reardon *et al*[38]

Chumanov *et al*[27] have suggested that the hamstrings are most susceptible to injury during the late swing phase of gait.[11] Our observation of hip flexion and forward progression of the shank (ie, movement from flexion towards extension) as characteristic features of 'running'-related HSIs supports the work of Chumanov *et al*.[27] Kenneally-Dabrowski *et al*[39] have also prospectively demonstrated greater extension moment at the hip and power absorption at the knee during that late swing phase in elite Rugby Union players who would subsequently incur HSIs. Trunk and hip flexion cause further lengthening of the hamstring muscles, which may increase the risk of injury.[40] This may place the hip extensors at a mechanical disadvantage.[41]

In addition, a factor that may be underconsidered is the relevance of trunk position. In each injury that we describe, the trunk was flexed at the IF. Additionally, all 'running' injuries involved trunk rotation at the IF, with 75% involving ipsilateral rotation. Prospective studies by Schuermans *et al*[42] and Kenneally-Dabrowski *et al*[39] noted greater ipsilateral trunk flexion during the swing phase of running in athletes who subsequently sustained an acute HSI in the following season. The contribution of excessive trunk rotation to the mechanism of 'running'-related HSI has not previously been reported on. We posit that trunk rotation is likely to be a manifestation of 'overstriding' and may increase the net negative (ie, eccentric) work required by the hamstring muscles during the terminal swing phase, thus potentially increasing the risk of HSI. However, we acknowledge that electromyographic and kinematic analyses would be required to verify this.

Table 3 Player action at the index frame (probable injury event)

	Player action	If running			If changing direction		If in tackle			Contact at injury		
Case	**Action**	**Velocity**	**Gait cycle**	**Speed**	**Angle**	**Direction**	**Who**	**Height**	**Direction**	**Contact**	**Type**	**Ruck**
Running												
1	Running in possession	Accel	Late swing	High	–	–	–	–	–	No	–	–
2	Running in possession	Accel	Initial contact	High	–	–	Tackled by opponent	Above waste	From side	Yes	Indirect	
3	Passing	Accel	Late swing	High	–	–	–	–	–	No	–	–
4	Turning	Accel	Late swing	High	>90 degrees	Away from injured side	Tackling opponent	Above waste	From side	No	–	–
5	Running in possession	Accel	Terminal stance	High	–	–	–	–	–	No	–	–
6	Running without possession	Accel	Late swing	High	45–90	Away from injured side	–	–	–	No	–	–
7	Running without possession	Accel	Late swing	Low	0–45	Away from injured side	–	–	–	No	–	–
8	Running in possession	Accel	Late swing	High	45–90	Away from injured side	–	–	–	No	–	–
Kicking												
9	Kicking	Steady	–	Low	0–45	Away from injured side	–	–	–	No	–	–
Decelerating												
10	Stopping	Decel	Late swing	High	0–45	Away from injured side	–	–	–	No	–	–
11	Turning	Decel	Late swing	Low	0–45	Away from injured side	–	–	–	No	–	–
12	Decelerating	Decel	Late swing	Low		–	–	–	–	Yes	Indirect	–
Tackle												
13	Running in possession	–		–	–	–	Tackled by opponent	Above waist	From side	Yes	Indirect	–
Ruck												
14	Contesting ruck	–	–	–	–	–	Tackling opponent	Above waste	From front	Yes	Indirect	Yes
15	Contesting ruck	–	–	–	–	–	Tackled by opponent	Above waste	From front	Yes	Indirect	Yes
16	Contesting ruck	–	–	–	–	–	Tackled by opponent	Above waste	From front	Yes	Indirect	Yes
Direct trauma												
17	Landing	–	–	–	–	–	Tackled by opponent	Above waste	From side	Yes	Direct	–

Decelerating

HSIs are often considered to occur during high-speed running and acceleration rather than deceleration.[43 44] However, we report three cases (18%; 3/17) whereby HSIs were sustained during a sudden deceleration—to our knowledge, this mechanism of HSI has not been previously described. In each of the three cases, the injured player decelerated suddenly in response to the actions of surrounding players. In all instances (3/3), the injured player was in a position of trunk and hip flexion, with the ipsilateral knee moving towards extension (1/3) or in a position of shallow knee flexion (2/3). This lengthened position of the hamstring muscles across two joints may heighten the risk of HSI during deceleration, especially considering that rapid hamstring contraction is integral to efficient deceleration.[45]

Kicking

One HSI (6%; 1/17) was sustained during a kicking action. Kicking has been reported as the mechanism of injury in 7%–19% of HSIs sustained in field sports,[7 46 47] with kicking injuries in rugby involving greater time loss than those sustained while running.[7] In a recent 15-year prospective study of kicking injuries in professional Rugby Union, Lazarczuk *et al*[48] reported that 33% of all kicking injuries involved the hamstring muscles. A significant reduction in neural activation during eccentric knee flexor contraction has been demonstrated following a repeated drop punting task in Australian football players,[49] a style of kick similar that which we have described. The injured player in our study was playing at fullback, which is the player position that completes the most kicks of any position, except for the scrum half and the out half.[48] The 'kicking' HSI in our study was sustained during a 'kick and chase',[48] which is characterised by a position of trunk flexion and ipsilateral (ie, injured limb) hip flexion, with a rapid active knee extension to punt the ball. This 'kicking' HSI mechanism replicates the 'stretch-type' HSI mechanism.[13]

Tackle

One HSI (6%; 1/17) was sustained during a tackle. In this case, the ball carrier was turned and propelled backwards by two tacklers in sequence. To try and counteract the momentum of the opposing players, the injured player extended his knee (in an effort to gain traction with the supporting surface). While doing

Table 4 Biomechanical position of the injured player at the index frame (probable injury event)

	Trunk			Hip (injured)				Hip (uninjured)			Knee (injured)		Knee (uninjured)
Case	Sagittal	Coronal	Transverse	Sagittal	Sagittal motion	Coronal	Transverse	Sagittal	Coronal	Transverse	Sagittal	Sagittal motion	Sagittal
Running													
1	Flexion	Neutral	Ipsilateral	Flexion	Extending	Neutral	Neutral	Extension	Unclear	Unclear	Extension	Extending	Flexion
2	Flexion	Neutral	Contralateral	Flexion	Extending	Neutral	Neutral	Neutral	Neutral	Unclear	Extension	Extending	Flexion
3	Flexion	Ipsilateral	Ipsilateral	Flexion	Extending	Neutral	Neutral	Extension	Neutral	Neutral	Extension	Extending	Flexion
4	Flexion	Contralateral	Ipsilateral	Flexion	Extending	Neutral	Neutral	Extension	Neutral	Neutral	Extension	Extending	Flexion
5	Flexion	Neutral	Contralateral	Extension	Extending	Neutral	External rotation	Flexion	Neutral	Neutral	Flexion	Extending	Flexion
6	Flexion	Neutral	Ipsilateral	Flexion	Extending	Abduction	External rotation	Extension	Neutral	Neutral	Extension	Extending	Flexion
7	Flexion	Neutral	Ipsilateral	Flexion	Extending	Neutral	External rotation	Extension	Neutral	Neutral	Extension	Extending	Flexion
8	Flexion	Neutral	Ipsilateral	Flexion	Extending	Neutral	Neutral	Extension	Neutral	Neutral	Extension	Extending	Flexion
Kicking													
9	Flexion	Neutral	Neutral	Flexion	Extending	Neutral	Internal rotation	Extension	Neutral	Neutral	Extension	Extending	Flexion
Decelerating													
10	Flexion	Neutral	Neutral	Flexion	Extending	Neutral	Neutral	Flexion	Unclear	Unclear	Extension	Extending	Flexion
11	Flexion	Contralateral	Neutral	Flexion	Extending	Neutral	External rotation	Flexion	Abduction	External rotation	Flexion	Extending	Flexion
12	Flexion	Neutral	Ipsilateral	Flexion	Extending	Unclear	Unclear	Flexion	Unclear	Unclear	Flexion	Extending	Flexion
Tackle													
13	Flexion	Neutral	Ipsilateral	Flexion	Flexing	Abduction	External rotation	Flexion	Unclear	Unclear	Flexion	Extending	Flexion
Rucking													
14	Flexion	Ipsilateral	Unclear	Flexion	Flexing	Neutral	Neutral	Flexion	Neutral	Neutral	Extension	Extending	Flexion
15	Flexion	Ipsilateral	Neutral	Flexion	Flexing	Neutral	Neutral	Flexion	Abduction	Neutral	Extension	Extending	Flexion
16	Flexion	Ipsilateral	Neutral	Flexion	Flexing	Abduction	External Rotation	Flexion	Unclear	Unclear	Extension	Extending	Unclear
Direct Trauma													
17	Neutral	Neutral	Neutral	Neutral	–	Neutral	Neutral	Neutral	Neutral	Neutral	Flexion	–	Extension

this, his trunk was forced downwards into a flexed and ipsilateral rotated position by the two opposing players. The injured player sustained a grade 3 HSI to the semimembranosus tendon. This position replicates the 'stretch-type' mechanism described in other sports,[13] while we posit that the addition of a transverse plane torque (ipsilateral trunk rotation) further increased the stretch on the musculotendinous unit.

Rucking

Three injuries (18%; 3/17) were sustained during rucking. The three injuries that we report were all sustained as the player was 'jackaling'—defined as 'competing for the ball using the hands'.[50] In these instances, the (injured) player was forced into trunk flexion on an extended knee. All cases were also characterised by an externally induced ipsilateral trunk lateral flexion – —two of which were the result of contact by a player on the opposing team who was attempting to forcefully remove the (injured) player from the ruck area.

In their analyses of the mechanisms of adductor longus injuries, Serner *et al*[25] suggested that high muscle activation at long muscle length precedes tissue failure.[27] The injuries sustained during 'rucking' all involved an externally applied force creating eccentric work demands on the muscle, whereby forced extremes of trunk, pelvis and hip positioning increased implied stretch on the hamstring muscles.

The location of the HSI sustained during rucking that we have described replicates the 'stretch-type' mechanism described in other sports such as dancing and water-skiing and has a similarly high time-loss burden.[9] Despite resulting in severe HSI, this mechanism has not been previously reported on in the published literature. Despite the small number of cases presented, this may be a distinct HSI mechanism specific to Rugby Union. This implies that the act of 'jackaling' bares particular risk for severe HSI. Modification to physical and technical approaches, in addition to consideration of adapting rules pertaining to the ruck may be worthy of consideration in minimising the risk of severe HSI associated with this game-related task.

Direct trauma

One HSI (6%; 1/17) was sustained as a result of direct trauma to the muscle. It is possible that visual video analysis may underestimate the prevalence of this type of HSI due to the difficulty in determining more subtle contacts sustained during match-play. It should be noted, however, that though atypical, muscle strain injuries can occur as a result of direct contact—compression or crushing—and that injuries that initially present as a contusion, or a 'dead leg' may actually involve a muscle strain injury and should be managed accordingly.[51]

Implications for rehabilitation

Our observations suggest that HSIs in rugby have multimodal injury mechanisms and should be considered from the perspective of several joints and planes of movement. While traditional HSI rehabilitation and injury prevention protocols have focused primarily on the narrow function of the hamstring muscles as knee flexors, and in particular, eccentric activity, we contest that approaches that focus entirely in this manner may fail to address the multiplane positional strains that occur in Rugby Union and which are likely to predispose to HSI. Furthermore, failure to appropriately consider trunk sensorimotor control during HSI prevention and rehabilitation protocols may explain the perennially high rates of HSIs in Rugby Union.

Based on our observations, we would recommend the use of exercises that combine hamstring loading at long lengths, but which also simultaneously challenge multiplanar trunk stability. Considering the injury burden associated with 'stretch-type' HSIs, rather than seeing tackling and rucking as necessary evils, time and attention should be devoted to the coaching of technical proficiency during the performance of these tasks to minimise HSI risk. The 'jackaling' position, which occurs during the ruck, where the player flexes at the hip and trunk in an attempt to steal the ball from an opponent, is pathognomonic of this particular type of HSI. Suboptimal positioning of the hip, feet and trunk may predispose the player to HSI while 'jackaling', whereby the player's centre of mass is below the level of his hips.[33] Hendricks *et al*[22] suggest the use of a scoring system to analyse contact events in rugby and retrospective analysis of poor technical execution, leading to injury may further inform coaching and HSI prevention initiatives. It is suggested that these tasks are considered a 'motor skill', with athletes encouraged to practice maintaining their joints in mid-range to protect the muscle from potential overstretch events and retain a margin for error to absorb force in contact.[52] Deliberate coaching and establishment of the best approach to safely perform these tasks in a competent manner may reduce the risk of HSI and should complement the protective application of tensile load during hip extension exercises, which aim to develop tissue resilience to strain.

Limitations

All participants in our study were male professional Rugby Union players. Similar analyses of HSIs occurring in different populations (female players, other sports, varying levels) are required. Sixty-seven per cent of the HSIs recorded in the Leinster Rugby injury surveillance database across the 2015/2016 to 2017/2018 seasons were excluded because video footage did not exist of the injury incident (n=20), the mechanism of injury was insidious or latent in onset (n=12) or because consensus could not be reached among the analysts on the IF (n=2). Considering this, we acknowledge that our analysis of 17 acute HSIs can be considered as a case series of individual injuries and does not provide a complete picture of all the potential mechanisms of HSIs in professional men's Rugby Union. Hence, a direct replication of our study using a bigger sample of injuries across numerous professional clubs is warranted. A greater proportion of excluded cases occurred during training than of those included (42% vs 12%). This was due to incomplete training footage. It is also posited that players were more likely to withdraw from training due to insidious hamstring pain, than during a game. We acknowledge that this is likely to bias our results to injury mechanisms occurring during match-play.

The video quality, resolution and angles were limitations to this study. To optimally describe multiplanar kinematics, multiple camera angles would be required. However, in a majority of cases that we describe, only a single camera angle of the injury event was available. We acknowledge that the exact moment when a HSI was sustained cannot be 'pin-pointed' from video analysis; therefore, the time point identified as the IF (the probable injury event) was an estimate based on the initial independent and then collective subjective analysis of the three analysts. Even where HSI has occurred during 3D motion analysis and muscle-tendon lengths and force calculated, the timing of injury and, therefore, exact injury mechanism can only be speculated based on our knowledge of tissue failure from animal studies and neuromuscular latencies.

What are the findings?

- ⇒ Hamstring strain injuries (HSIs) in professional Rugby Union were sustained during a number of actions, including 'running', 'decelerating', 'kicking', a 'tackle' and 'rucking'.
- ⇒ Hamstring muscle lengthening, characterised by trunk flexion and active knee extension, was deemed to be a fundamental characteristic of the mechanisms of acute HSIs in Rugby Union.
- ⇒ Ipsilateral trunk rotation was deemed to be a characteristic feature of the mechanism of acute HSIs in professional Rugby Union.

How might it impact on clinical practice in the future?

- ⇒ Clinicians should be suspicious of acute HSI in Rugby Union players if the reported injury mechanism includes a combination of trunk flexion and active extension of the knee joint.
- ⇒ Continued coaching of optimal ruck technique is important to prevent players being forced into the positions deemed to be associated with HSI during this specific game-related task—and in particular during 'jackaling'.
- ⇒ Exercises that combine hamstring loading at long lengths while concomitantly challenging multiplanar trunk stability may be effective in mitigating the risk of HSIs—however, this requires scientific validation.

Higher frequency frame rates than that available to the analysts, if available, may allow for more accurate IF determination. The engagement of patients in research is an important issue and could have enhanced our observations; hence, we advocated that future studies should, if possible, include players in the research process; they may be able to provide valuable input to help better detail the mechanisms of injury. Contemporaneous, rather than retrospective, review of videos may also be of benefit in injury management and in future studies.

CONCLUSION

HSIs in Rugby Union do not exclusively occur during sprinting. We identified a number of injury mechanisms including: 'running', 'decelerating', 'rucking', 'kicking', 'tackle' and 'direct trauma'. Our observations suggest that active hamstring muscle lengthening, characterised by trunk flexion and relative knee extension appear to be a fundamental characteristic of the mechanisms of acute HSIs in Rugby Union.

Twitter Fearghal Kerin @fearghalkerin, Peter Tierney @petertierney93, Ulrik McCarthy Persson @Ulrikmccarthype and Eamonn Delahunt @EamonnDelahunt

Contributors The idea for the study was co-developed by FK, ED, GF, PT, UMP and GDV. Data for the study were sourced by FK and PT. The injury assessment form (online supplemental file 1) was developed by Fearghal Kerin and approved by ED and F. ED, FK and GF analysed all the videos and reached consensus on the details of the injury assessment forms. The consensus meeting was mediated by UMP. ED developed the qualitative description of each injury case (online supplemental file 2). ED and FK drafted the initial manuscript, which was edited and agreed upon by all authors.

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ORCID iDs
Fearghal Kerin http://orcid.org/0000-0002-7300-4120
Peter Tierney http://orcid.org/0000-0002-6216-9368
Eamonn Delahunt http://orcid.org/0000-0001-5449-5932

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